Interactions of Nutrient and Carbon Cycles and Trace Gas Exchange with Land Use Change and Fire In the Cerrado of Central Brazil

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Abstract

Land use changes accompanied by fire frequently occur in the Brazilian cerrado. Here we report measurements in the cerrado of the effects of fire and land use change on the composition and persistence of litter and soil organic carbon and nitrogen and related changes in the soil-atmosphere fluxes of selected trace gases (CO_2, CO, N_2O, NO). The studies include two classes of cerrado, cerrado *stricto senso* (20-50% canopy cover) and *campo sujo* (open, grass-dominated), located in the research and ecological reserve operated by IGBE, located 35 km south of Brasilia, Brazil and in a 20-year-old cattle pasture at an EMBRAPA Cerrados field research site located 25 km northwest of Brasilia.

Introduction

Savanna ecosystems are controlled by the interactions between water and nutrient availability. The savannas of Central Brazil (cerrado) are the second most extensive plant formation in tropical South America with two million km^2 of area, which accounts for 22% of the total area of Brazil. The cerrado is a tropical savanna in which herbaceous vegetation (mainly C_4 grasses) coexists with trees and shrubs. In general, cerrado soils are old, deep, well drained, well structured, acidic, have low fertility, and high iron and aluminum contents. Mean rainfall is about 1500 mm per year with well-defined wet (October - March) and dry (April - September) seasons. The term cerrado represents three general physiognomic types of vegetation reflecting variation in degree of tree cover: campo sujo (open, grass-dominated), cerrado *stricto sensu* (ss) and cerradão (closed forest). In campo sujo <10% of the soil surface is shaded, whereas in the closed forest >90% of the soil surface is shaded. The degree of soil shading in cerrado ss ecosystems is intermediate between that of campo sujo and cerradão. Extensive areas of cerrado have been converted to pastures and grasslands by frequent burning or clearing.

Our objectives were to assess the effects of prescribed fires on: (1) soil fluxes of CO_2 and CO, and (2) soil fluxes of NO and N_2O and N mineralization and immobilization. Biological production of CO_2 in soils results from the decomposition of soil organic matter (SOM) and from root respiration. Potential abiological sources of CO and NO include thermal- and photo-degradation of litter and SOM and soil microbial processes could potentially consume both gases. Chemodenitrification is a possible abiotic source of NO and N_2O. Potential microbially-mediated sources of NO and N_2O include nitrification and denitrification. The studies are focusing on two classes of Cerrado, campo sujo and cerrado ss, located at the research and ecological reserve operated by IGBE, located 35 km south of Brasilia (15°56'S, 47° 53' W). The burned areas on which we focus have been subjected to prescribed fires every two years since 1992 at the end of the dry season (late September).

Methods

CO and N_2O fluxes were estimated with static chamber techniques, and NO and CO_2 fluxes were estimated with dynamic chamber techniques. NO, CO_2, and N_2O fluxes were estimated with dark chambers and CO fluxes were estimated both with dark and transparent (borosilicate glass) chambers.

CO concentrations were quantified by gas chromatography (GC) with a Trace Analytical RGA-3. N_2O concentrations were quantified by GC with a Shimadzu GC-14A with electron capture detector. CO_2 concentrations were monitored with a LiCor 6200 photosynthesis system with infrared gas analyzer and NO concentrations were monitored with a Unisearch LMA-3 chemiluminescent detection based system.

N mineralization rates were measured using *in situ* soil incubations (0-5 cm depth) in PVC cores. Soils were collected at the beginning of incubation period and one month later.

To study the effect of soil moisture on the trace gas fluxes, in mid dry season (August 2000) water was added to the soil surface in the unburned campo sujo plot simulating 2 cm and 18 cm of rain. Another area was used as control. Flux measurements were made before and 30 min, 1, 2, 3, 5 days after water addition(n=3 for each treatment).

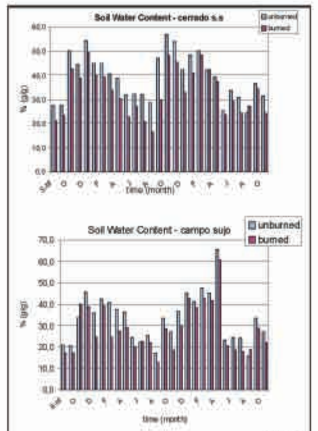


Figure 1

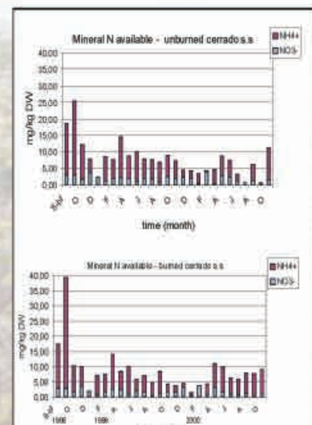


Figure 2

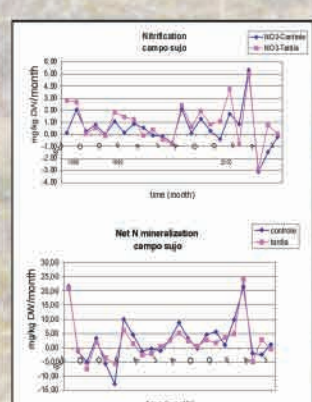


Figure 3

Results

Soil Water Content.
Gravimetric soil water content followed the seasonal rainfall pattern and ranged from less than 20% to greater than 60% (Figure 1).

Soil water content was greater in unburned soils than in burned soils (Fig 1.).

Soil water content was generally greater in cerrado ss soils (Fig. 1).

N mineralization.
Ammonium was generally the dominant form of soil mineral N in both the cerrado ss (Figure 2) and campo sujo (data not shown).

The burned campo sujo soils generally had less total mineral N than the unburned soil (data not shown). Burned and unburned cerrado ss soils generally had similar amounts of total mineral N (Fig. 2).

Nitrification rates were low in both vegetation types (e.g., Figure 3).

Both N mineralization and nitrification rates are highly variable throughout the year (Figure 3), probably in response to wetting and drying cycles.

N_2O fluxes.
N_2O fluxes were generally undetectable with only a few exceptions, mostly during the wet season (Figure 4).

On the dates when N_2O flux was detected there was high spatial variability (Fig. 4). In some cases high N_2O fluxes correlated with peaks in nitrification (e.g., Fig. 4).

NO fluxes.
Addition of water to unburned campo sujo soils during the dry season caused a pulse (10X) of NO flux which was very short lived (Figure 5).

Fire alone during the dry season also caused a short term stimulation of NO flux but the magnitude was much less than that caused by water addition (Figure 6).

CO_2 fluxes.
CO_2 fluxes responded to seasonal variations in rainfall with higher CO_2 fluxes during the wet season (Figure 7).

CO_2 fluxes were generally higher in burned campo sujo than in unburned campo sujo whereas unburned cerrado generally exhibited higher CO_2 flux than burned cerrado (Fig. 7).

Addition of water to dry soil caused a roughly 5X stimulation of CO_2 flux that was very short-lived (Figure 8).

Fire alone had a very minimal effect on CO_2 flux from dry soils (Figure 9).

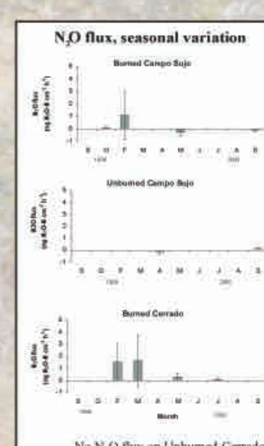


Figure 4

CO fluxes.
CO fluxes vary seasonally, with higher fluxes occurring during the late dry season (Figures 10 and 11).

CO fluxes are strongly dependent upon light. Integrated UVB light levels are also indicated on Figures 10 and 11.

CO production after fire dramatically increased for at least a month after burning for both campo sujo and cerrado ss (Figures 10 and 11).

Consumption of CO, measured with dark chambers, was highest in burned cerrado ss. (Figure 10)

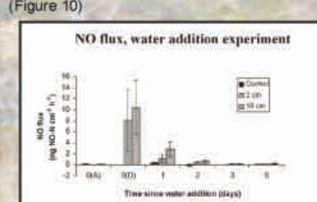


Figure 5

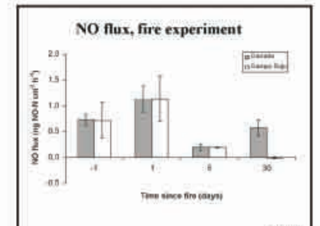
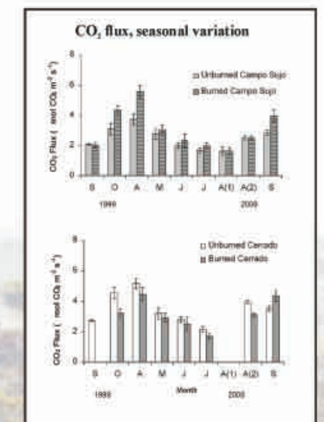


Figure 6



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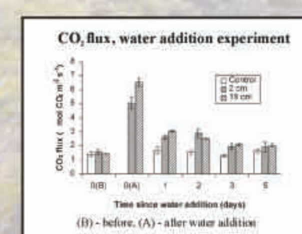

Figure 8

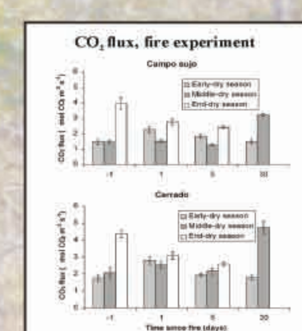

Figure 9

Discussion

N mineralization rates in these cerrado ecosystems were generally similar to other seasonal ecosystems but lower than rates found in tropical forests.

There are very few published measurements of N_2O flux during the wet season from similar ecosystems to compare the present results with. N_2O emissions from an ammonium-dominated Venezuelan savanna with very similar ammonium concentrations during the wet season were about the same magnitude as those observed in the present study and were spatially patchy [Sanhueza et al., 1990].

Many other studies have demonstrated large, short-lived pulses of NO flux following burning and/or addition of water to dry soils [e.g., Davidson, 1992; Poth et al., 1995; Levine et al., 1996; Anderson and Poth, 1998]. Parsons et al. [1996] pointed out the problems with comparing net nitrification rates determined over time scales of weeks with NO fluxes that likely respond to processes operating on much shorter temporal scales.

Higher soil moisture levels and litter inputs probably both contribute to the higher CO_2 fluxes observed in the unburned cerrado ss as compared to the burned cerrrado ss. Frequent fire increases the dominance of grass by reducing woody plants in the campo sujo. Fire-associated increases in grass roots in the upper soil layers could explain the higher CO_2 fluxes measured in the burned campo sujo vs the unburned campo sujo. Stimulation of CO_2 fluxes by moisture addition to dry savanna soils had been demonstrated by many investigators [e.g., Hao et al., 1988; Poth et al., 1995; Zepp et al., 1996; Anderson and Poth, 1998] and demonstrates that soil moisture is one of the major controllers of biological activity in these systems.

Net CO flux is a balance between production and consumption processes. CO flux seasonally varies presumably due to variations of solar irradiance, soil moisture, soil temperature, and available litter for photoproduction. Campo sujo is more open allowing greater photoproduction of CO from plant litter than in cerrado ss. High leaf litter inputs and low soil moisture in August and September correspond with high CO production and low CO consumption before burning. The high CO flux after burning is likely due to photoproduction of CO from blackened and dead plant material [e.g., Zepp et al., 1997]. Fluxes of CO correspond to levels of UV-B received, which accounts for the drop in CO flux 5 days after burning and the subsequent increase 30 days after burning. Consumption of CO is likely related in a complex way to variations in soil moisture, soil temperature, soil nutrients, and microbial population variations [e.g., Conrad and Seiler, 1985]. In these cerrado sites CO consumption appears to be favored by lower soil temperatures and higher soil moisture levels.

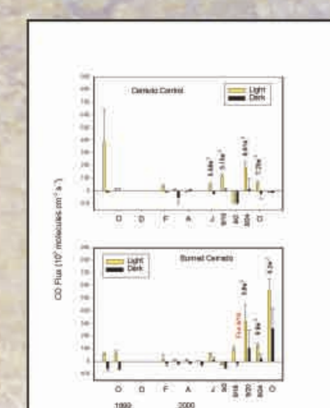

Figure 10

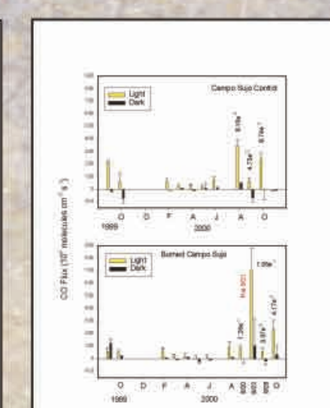

Figure 11

Conclusions.

Soil moisture appears to be the most important controller of both CO_2 and NO fluxes.

Solar radiation appears to be the most important controller of CO fluxes.

Burning appears to have important but short term effects on CO and NO fluxes.

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